Received: 7 August 2022 | Accepted: 9 March 2023

DOI: 10.1111/evj.13945

ORIGINAL ARTICLE

Equine Veterinary Journal WILEY

Subchondral lucencies of the medial femoral condyle in yearling and 2-year-old Thoroughbred sales horses: Prevalence, progression and associations with racing performance

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Funding information
Grayson-Jockey Club Research Foundation; Keeneland Association Ltd; Fasig-Tipton Ltd; Barbara Banke; Bridlewood Farm; Flaxman Holdings; Maria Niarchos; John & Jerry Amerman; Foxwood Stables; Three Chimneys Farm; Ashford Stud; John Magnier; Dr Mark Dedomenico; Consignors & Commercial Breeders Association (Lexington, Kentucky); Marty & Pam Wygod; Gary West; Dr Ryan Carpenter; Antony Beck; Gainesway Farm; Spendthrift Farm; Denali Stud; Victoria Chapman

Abstract

Background: Subchondral lucencies (SCLs) in the distal aspect of the medial femoral condyle (MFC) of young Thoroughbred horses are a source of controversy on presale radiographs. There is limited scientific evidence regarding the risk of progression and impact on future racing performance.

Objectives: To (1) identify the prevalence of MFC SCLs on sales repository radiographs in yearling and 2-year-old Thoroughbreds; (2) identify any association between grade of MFC SCL and future racing performance and (3) monitor changes in MFC SCL grades between yearling and 2-year-old sales.

Study design: Prospective cohort study.

Methods: Radiographs were obtained with consignor permission from a 2016 yearling sale and five 2017 2-year-old sales. Stifle radiographs were evaluated and MFC SCLs graded on a scale of 0–3. Axial MFC lucencies were recorded separately. Maximum MFC grades per horse were analysed for associations with racing performance outcomes, adjusted for sex, to the end of the horses' 4-year-old racing year. Analysis was via logistic, negative binomial or linear regression as appropriate, with the threshold for significance set at $\alpha = 0.05$.

Results: Radiographs from 2508 yearlings (5016 stifles) and 436 2-year-olds (872 stifles) were included in the study. MFC SCLs of grades 1–3 were observed in 242 (9.65%) yearlings and 49 (11.2%) 2-year-olds. Bilateral MFC SCLs of grades 1–3 were observed in 54 (2.2%) yearlings and 12 (2.8%) 2-year-olds. Grade 1 MFC SCLs in yearlings either remained unchanged (14/31), progressed to a grade 2 (6/31) or resolved (11/31) by the 2-year-old sale. Grade 2 MFC SCLs in yearlings remained unchanged (6/10), progressed to a grade 3 (2/10) or improved to a grade 1 (2/10). Yearlings with a grade 3 MFC SCL had a 78% probability of starting a race (95% confidence interval [CI] 58.2–89.6%), compared with an 84% probability of racing for grade 0 yearlings (95% CI 82.7–85.8%). Six of the seven yearlings with axial MFC lucencies raced.

Main limitations: This study may underestimate the prevalence of severe lesions in the general yearling population of U.S. Thoroughbreds. However, the convenience sample used is representative of the population of interest at sales. The study design could not address exclusions prior to sale.

Conclusions: Grade 1 MFC SCLs are the most common type seen in yearling and 2-year-old sales horses. The majority of yearling grade 1 MFC SCLs resolved or remained static by 2-year-old sales. It was also possible for grade 2 and 3 MFC SCLs to improve one grade between sales. Fewer sales yearlings with a grade 3 MFC SCL raced, but in those that did race there was no evidence of worse performance compared to unaffected peers. Axial MFC lucencies did not affect racing performance.

KEYWORDS
cyst, horse, lucency, presale, radiology, stifle

1 | INTRODUCTION

The prognostic significance of radiological findings on presale examinations is a concern to the Thoroughbred industry,[1] and the radiological appearance of subchondral lucencies (SCLs) in the equine medial femoral condyle (MFC) and their potential impact on athletic performance has been a source of controversy.[2–8] The incidence of lesions in the MFC ranges from 0.8% to 16% depending on how a lesion is defined.[2–8] Subchondral lucencies (which may be shallow in nature), condylar flattening, cysts in the axial MFC and cysts on the central MFC surface are known to behave differently, but are often catagorised together, making the significance of each lesion difficult to understand.[2–8] Radiological abnormalities of the stifle can change with age in young horses, and SCLs most commonly occur in the MFC within the first 18 months of life.[9–11] Both substantial radiological improvement and worsening of MFC SCLs have been documented in growing horses.[3,9] However, there is limited scientific evidence regarding the frequency of progression of SCLs in sales yearlings and 2-year-olds and their impact on racing careers.[12,13]

This study aimed to objectively evaluate yearling and 2-year-old Thoroughbred sales repository radiographs from a large percentage of the U.S. population, to clearly define the prevalence and lesion characteristics of MFC SCLs and to analyse associations between the lesion grades and racing performance. In horses presented at both sales, the study aimed to identify differences in grade of MFC SCL between one and 2 years of age. It was hypothesised that yearlings with grade 3 lesions would have reduced racing starts and that there would be no progression of lesion severity with age.

2 | MATERIALS AND METHODS

2.1 | Data collection

2.1.1 | Recruitment and enrolment

Consent for study inclusion was sought from consignors of all horses at the 2016 Keeneland September Yearling Sale (Lexington, KY, USA), and from the five major subsequent 2-year-old sales in 2017: Fasig-Tipton Gulfstream, Ocala Breeders' Sales (OBS) March, OBS Spring, Fasig-Tipton Maryland and OBS June (Ocala, FL, USA). Horses for which study consent was granted at the yearling sale required new research consent from their respective 2-year-old consignors to be eligible for 2-year-old sale radiograph inclusion. Radiographs for which permission was granted were downloaded in DICOM format after the completion of each sale.

2.1.2 | Radiological evaluation

Six radiographs acquired as part of the standard sales repository protocol were evaluated for each horse: the lateromedial (LM), caudocranial elevated 10°–20° proximodistal (CdCr) and caudolateral 30°-craniomedial oblique (CdLCrMO) projections of the left and right stifles. The radiological appearance of each MFC was categorised into one of four grades as depicted by the example radiographs in Figures 1–4. Grades were recorded for the MFC appearance on CdCr and CdLCrMO images and the highest grade was taken to represent that MFC. Grade definitions are tabulated in Table S1.

Lucencies located within the axial aspect of the MFC adjacent to the medial intercondylar eminence of the tibia, as depicted in Figure 5, were recorded separately from the MFC SCL grading system. MFCs with an axial lucency were graded according to the appearance of the central distal articular portion of the condyle, as for all other stifles. An additional record was made of the presence and size of the axial lucency.

The majority of radiographs were read by two veterinarians with 18 and 10 years' experience in repository radiology, respectively (DK and FP). Prior to evaluating the study radiographs, all four involved veterinarians underwent a period of training during which they discussed the grading system and applied group consensus to a sample of images. Each veterinarian then independently evaluated the same sets of CdCr and CdLCrMO stifle radiographs for 10 MFCs, to test interobserver agreement. During evaluation of the study images by individual veterinarians, questionable findings were graded via consensus when necessary. Radiographs were viewed using DICOM

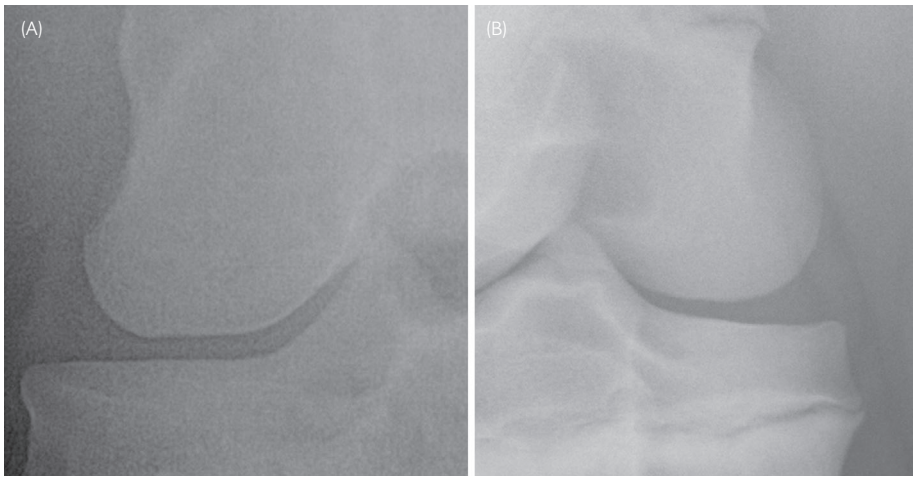

FIGURE 1 Radiographs showing the appearance of a grade 0 equine medial femoral condyle (MFC) in a Thoroughbred yearling on CdCr (A) and CdLCrMO (B) projections. The grade 0 MFC has no subchondral lucency. Flattening of the distal articular contour of the condyle is allowed.

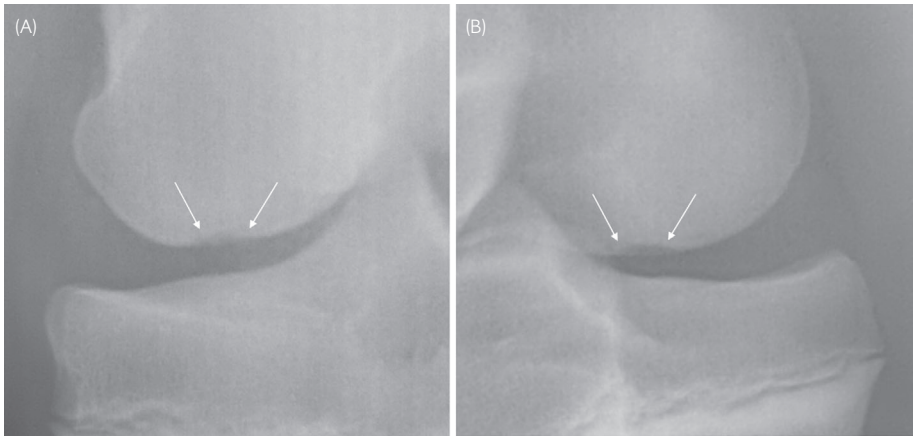

FIGURE 2 Radiographs showing the appearance of a grade 1 subchondral lucency (SCL, white arrows) in the distal aspect of the equine medial femoral condyle (MFC) in a Thoroughbred yearling on CdCr (A) and CdLCrMO (B) projections. The grade 1 MFC SCL is a mild, shallow, crescent-shaped lucency with a proximodistal depth ≤3 mm and with an axial-abaxial width greater than its depth.

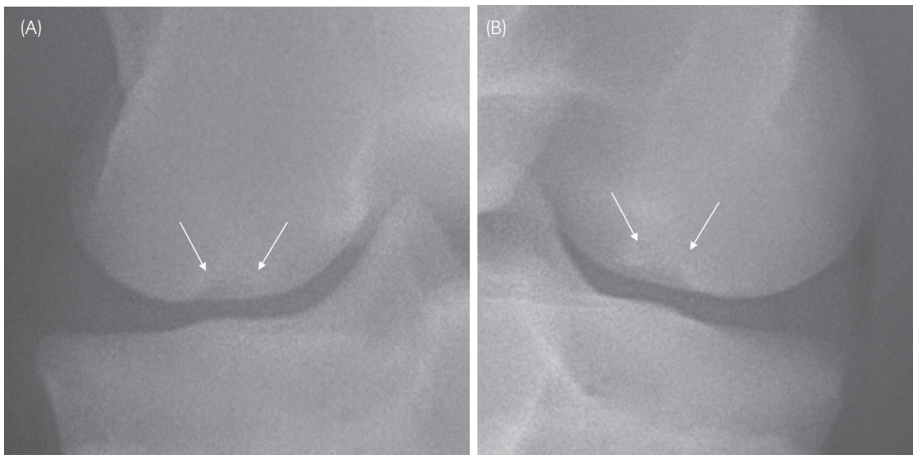

FIGURE 3 Radiographs showing the appearance of a grade 2 subchondral lucency (SCL, white arrows) in the distal aspect of the equine medial femoral condyle (MFC) in a Thoroughbred yearling on CdCr (A) and CdLCrMO (B) projections. The grade 2 MFC SCL is a moderate, dome-shaped lucency that extends through the subchondral bone, with a depth approaching that of its width.

viewing software OsiriX MD and Horos. Observers were blinded to sale and race results during evaluation of radiographs.

2.1.3 | Racing performance data

Racing performance data collection continued until the end of the horses' 4-year-old racing season. Racing data was obtained from Equibase Company LLC. Racing performance was measured via eight outcome variables.[14] Variables relating to race starts included: whether the horse started at least one race by the end of the 4-year-old racing year,[8,12] age at first start and total number of starts.[14,15] Variables relating to prizemoney included total earnings and earnings per start (USD).[8,16] International earnings were converted to USD using the exchange rate on the date of racing. Variables related to calibre of racing performance achieved included: career best start,

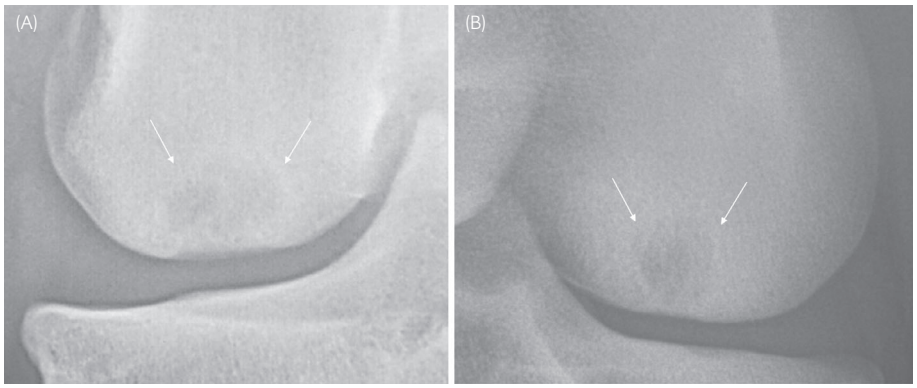

FIGURE 4 Radiographs showing the appearance of a grade 3 subchondral lucency (SCL, white arrows) in the distal aspect of the equine medial femoral condyle (MFC) in a Thoroughbred yearling on CdCr (A) and CdLCrMO (B) projections. The grade 3 MFC SCL is a large, spherical or ovoid cystic lesion that communicates with the central articular surface of the condyle.

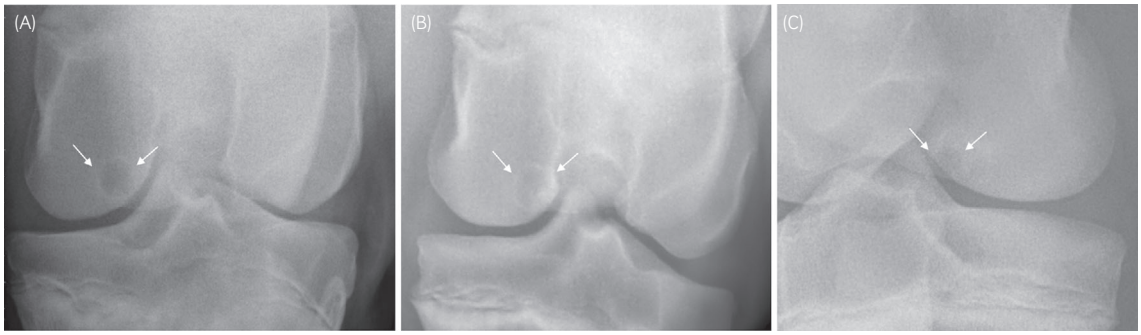

FIGURE 5 Radiographs showing spherical or ovoid lucencies in the axial aspect of the equine medial femoral condyle (MFC), adjacent to the medial intercondylar eminence of the tibia, in three different 2-year-old Thoroughbred horses on CdCr (A,B) and CdLCrMO (C) projections. Axial MFC lucencies were recorded and analysed separately from the MFC subchondral lucency grading system because they do not involve the central weightbearing portion of the distal MFC. All three of these horses are grade 0 MFC SCL for the central distal articular portion of the condyle.

weighted Listed and Group race starts and Class Performance Index.[12] Best start was a binary outcome for whether a horse started at least one race at Listed or Group level. Weighted Listed and Group race starts was the sum total of weighted starts, including each Listed race (1 point), Group 3 race (2 points), Group 2 race (3 points) and Group 1 race (4 points), respectively. Class Performance Index was a lifetime ratio based on an individual horse's average earnings per start, divided by the average earnings per start of all other horses of the same sex and birth year.

2.1.4 | Nonstarter follow-up information

Any horse that did not start at least one race was considered a nonstarter. Follow-up information for nonstarters was sought via email and telephone communication with the connections of each horse, using a flow-chart conversation framework that was designed to obtain increasing levels of detail while minimising bias (Figure S1).

2.2 | Data analysis

Data analysis was performed via consultation with statisticians using the open-source statistical software package R, version 4.0.2 by RStudio. All reported confidence intervals (CIs) are 95% and $\alpha = 0.05$ was used as a threshold for significance across all tests. No adjustments to reported p values were made for multiple tests performed across outcomes.

2.2.1 | Interobserver agreement

Agreement between all pairs of observers was assessed using Cohen's kappa with a squared weighting, reported as a group range.[17,18] Krippendorff's alpha for multiple observers with an ordinal method was also used, which is equivalent to the mean of Cohen's kappa between pairs. Unweighted Fleiss' kappa for multiple observers was used to calculate group agreement within each grade of lesion.[19]

2.2.2 | Radiological findings

Radiological findings were summarised using descriptive statistics, with frequency distributions at the stifle-level by age, by sex and by left and right hindlimb. Radiological findings were summarised at the horse-level by age, using maximum MFC grade per horse. The proportion of horses with grade >1 MFC SCLs at yearling age compared with the same proportion at 2 years of age was analysed

using McNemar's Chi-squared test with a continuity correction for low frequencies.

2.2.3 | Racing performance

Associations between yearling radiological findings and future racing performance were analysed, with each yearling assigned a horse-level categorical variable in the form of maximum MFC grade. This was the most severe MFC SCL appearance the horse had as a yearling, in either the left or right stifle. To test for a significant relationship between maximum MFC grade and the racing outcome, an analysis of variance *F*-test (for continuous outcomes) or a likelihood ratio test (for binary and count outcomes) was performed, and associated test statistics and *p* values were reported.

Regression analysis of associations between maximum MFC grade and racing performance outcomes controlled for horse sex, to adjust for differences in racing opportunities. Binary outcomes 'Started at least one race' and 'Career best start' were analysed using logistic regression. The count outcome 'Number of starts' was analysed using negative binomial regression. The remaining race performance variables were analysed using linear regression. The reference value for maximum MFC grade in all regressions was set to zero. For the racing outcome variable 'Started at least one race', all available horses were used. For other racing performance measures, only horses that started a race were included in the analysis.

Data transformations were used when necessary to better satisfy model assumptions, for example, normally distributed errors. Earnings related measures required log transformation, with all $0 earnings and $0 earnings per start set to $1. Class Performance Index required log transformation with all CPI of zero set to 0.05, which is half the minimum performance value of 0.1. Weighted Listed and Group starts required square root transformation.

Model estimates and CIs produced by single variable regression analyses were back-transformed to provide estimates that pertained to the original scale of the racing performance data, describing the average value of the outcome for each level of max MFC score.

3 | RESULTS

3.1 | Study enrolment

Repository radiographs for 2508 yearlings were used (Figure S1), which represented 10.9% of the annual foal crop and 36.0% of the 6963 North American yearlings sold at auction in 2016 (Jockey Club Information Systems Inc.). The age of the study yearlings on the first day of the sale ranged from 458 to 614 days old, with a median of 535 days old. Repository radiographs for 436 2-year-olds were used (Figure S2), representing 19.7% of the 2-year-olds sold at auction in North America in 2017.

TABLE 1 Distribution of the most severe radiological medial femoral condyle subchondral lucency (MFC SCL) grade in the left or right stifle per horse in Thoroughbred sales yearlings and 2-year-olds, where *N* represents individual horses.

MFC SCL grade	Number of yearlings, *N* (%)	Number of 2-year-olds, *N* (%)
Grade 0	2266 (90.4%)	387 (88.8%)
Grade 1	171 (6.8%)	30 (6.9%)
Grade 2	45 (1.8%)	14 (3.2%)
Grade 3	26 (1.0%)	5 (1.1%)
Total	2508	436

3.2 | Interobserver agreement

Overall ordinal agreement between the four veterinarians evaluating stifle radiographs was $K\alpha = 0.94$, (group range weighted $Ck = 0.88–1.00$, $p = 0.004–0.002$). Fleiss' kappa for group agreement within each grade of MFC lesion was $k = 1.00$ for grade 0 and grade 3, $k = 0.57$ for grade 1 and $k = 0.62$ for grade 2.

3.3 | Radiological findings

3.3.1 | Distribution of MFC SCL grades

MFC findings summarised at the horse-level are presented in Table 1. Supporting information contains the individual MFC findings for all 5016 yearling stifles and 872 2-year-old stifles (Table S2), the frequency distribution of MFC findings by left and right hindlimbs in each age group (Table S3) and MFC findings by horse sex (colts/geldings and fillies) in each age group (Table S4).

3.3.2 | Paired yearling and 2-year-old sales radiographs

Radiographs were available at both the yearling sale and a 2-year-old sale for 422 horses, enabling assessment of any change in the appearance of MFC SCLs between 1 and 2 years of age. Results are presented in Table 2.

Of the yearling grade 1 MFC SCLs, by 2 years of age 35.5% were a grade 0 and 45.2% remained a grade 1 (11/31 and 14/31, respectively). Thus, 80.7% of yearling grade 1 MFC SCLs had either resolved or remained unchanged at 2-year-old sale presentation. Overall, 19.4% of yearling grade 1 MFC SCLs progressed to a grade 2, that is, one in five yearlings with a grade 1 MFCL (6/31). When analysed by hindlimb side, 14% of left stifle and 24% of right stifle grade 1 MFC SCLs progressed to a grade 2 (2/14 and 4/17, respectively). For yearlings with grade 2 lesions, two (20%) improved to grade 1, six (60%) remained unchanged and two (20%) progressed to a grade 3. For yearlings with grade 3 lesions, two (66%) improved to a grade 2 and one (33%) remained unchanged. McNemar's test did not indicate a significant

TABLE 2 Distribution of medial femoral condyle subchondral lucency (MFC SCL) grades per stifle at 2-year-old sales (columns), relative to each stifle's respective MFC SCL grade at the yearling sale (rows), for 422 horses with paired yearling and 2-year-old Thoroughbred sales radiographs.

	MFC grade at 2-year-old sale, *N* (%)				
MFC grade at yearling sale	**Grade 0**	**Grade 1**	**Grade 2**	**Grade 3**	**Total stifles $n = 844$**
Grade 0	**775 (96.9%)**	21 (2.6%)	2 (0.2%)	2 (0.2%)	800 (100%)
Grade 1	11 (35.5%)	**14 (45.2%)**	6 (19.4%)	0 (0%)	31 (100%)
Grade 2	0 (0%)	2 (20%)	**6 (60%)**	2 (20%)	10 (100%)
Grade 3	0 (0%)	0 (0%)	2 (66.7%)	**1 (33.3%)**	3 (100%)
Total stifles	786	37	16	5	844

Note: Bolded values represent grades that remained static between sales.

TABLE 3 The distribution of radiological medial femoral condyle subchondral lucency (MFC SCL) grades for all study horses at the Thoroughbred yearling sales, by most severe finding per horse, with the accompanying proportion of horses that started at least one race by the end of their 4-year-old racing season and the probability of starting a race via logistic regression analysis controlling for horse sex (colt/gelding, filly).

Yearling MFC grade	Proportion raced (%)	Probability of starting a race, controlled for horse sex	SE for probability	95% confidence interval	*p* value	Number raced	Total yearlings, $N = 2508$
0	84.2	0.843	0.008	0.827–0.858	NA	1909	2266
1	87.1	0.872	0.026	0.813–0.914	0.314	149	171
2	91.1	0.913	0.042	0.790–0.967	0.203	41	45
3	76.9	0.776	0.081	0.582–0.896	0.352	20	26

difference in the proportion of yearling and 2-year-old horses with at least one non-normal MFC ($\chi^2 = 2.793$, df $= 1$, $p = 0.095$).

3.3.3 | Axial MFC lucencies

Seven yearlings had lucencies located in the axial aspect of the MFC, adjacent to the medial intercondylar eminence of the tibia (7/2508, 0.3%). These ranged in appearance from irregular lucencies to well-defined spherical or ovoid cystic lesions. One yearling was bilaterally affected. In all six yearlings, the affected stifles had a grade 0 appearance for the central articular aspect of the distal MFC. One yearling had a grade 1 MFC SCL in the contralateral stifle, the rest had grade 0 central MFCs bilaterally. Two of these yearlings presented again at 2-year-old sales and the axial MFC lucencies persisted in both cases. No new axial MFC lucencies were seen in 2-year-olds that did not have them as yearlings.

3.4 | Associations with racing performance

3.4.1 | Started at least one race

Overall, 85% of study yearlings started at least one race (2119/2508) and 15% had not raced by the end of their 4-year-old year (389/2508). The probability of yearlings with a grade 3 MFC SCL starting a race was lower than the probability of yearlings with grades 0–2 MFCs starting a race (77.6% vs. 84.3–91.3%) (Table 3). However, logistic regression analysis showed no statistically significant difference in the probability of starting a race for any category of MFC SCL ($p = 0.3$).

Of the entire registered North American foal crop born in 2015, 68.4% (15 770/23 043) had started a race by the end of their 4-year-old year and an additional 0.7% had their first race start aged 5 years or older (159/23 043) (Jockey Club Information Systems Inc.).

3.4.2 | Follow-up of non-starters

Follow-up information was obtained for 166 of 389 horses that never started a race (43% of nonstarters). For 84 nonstarters, the follow-up was partial; that is, either confirmation was given that the horse never raced but the reason for not starting was unknown, or confirmation was given that the horse was a broodmare but the reason for never racing was unknown, or the horse was identified as exported from the United States and the racing history was inaccessible. Follow-up information was complete for 82 nonstarters. Of these 82 horses; 66 did not make a race start for reasons related to performance, 10 did not race due to fatal or near fatal accidents unrelated to performance, 5 did not race due to medical events requiring euthanasia and 1 was purchased from the yearling sale for a nonracing discipline.

Of the 66 nonstarters with follow-up that indicated a performance-related reason for not racing; 45 involved lameness, 14 were deemed to have insufficient athletic talent, 3 had upper respiratory tract dysfunction, 1 did not start for behavioural reasons, 1 had severe exertional rhabdomyolysis, 1 had cervical vertebral malformation (wobbler) and 1 had recurrent exercise-induced pulmonary haemorrhage.

Of the 45 nonstarters that did not race due to an identified lameness, the clinical diagnosis involved the stifle region in 4 horses; in 3 cases the specific structure affected within the stifle was unknown and 1 horse was kicked in the stifle and had a persistent swelling at the site of external trauma. None of these four cases mentioned MFC SCL as a suspected cause of lameness. All MFCs in these four horses had a grade 0 appearance on yearling radiographs and none had 2-year-old sales radiographs. In all 45 nonstarters that did not race due to known lameness, there was 1 horse with a grade 2 MFC lucency on its yearling and 2-year-old radiographs; this horse did not race due to a sesamoid fracture.

In the 14 nonstarters that did not race because they were deemed too slow; 1 had a grade 3 MFC SCL as a yearling. The owner specifically stated that this cystic lesion had been monitored during training and it had improved radiologically and had never caused a clinical problem, although this was not confirmed by the authors. The other 13 horses that did not start due to lack of ability all had grade 0 MFCs.

Of the 84 nonstarters with partial follow-up where the reason for not racing was unknown, and the 223 nonstarters with no follow-up information; 5 had a grade 3 MFC SCL and 3 had a grade 2 MFC SCL. The overall distribution of MFC findings at the horse level in horses that raced compared with nonstarters can be found in Table S5.

3.4.3 | Age at first race start

Of the 2119 yearlings that raced, the mean age at first start was 1006 days old, that is, 2 years and 9 months (median 969 days, range 687–1725 days, lower quartile [Q1] 882 days, upper quartile [Q3] 1102 days). There was no significant difference in the average age at first start between horses with any grade of MFC SCL ($p = 0.3$) (Table S6).

3.4.4 | Number of race starts

The horses that raced had an average of 12.3 starts by the end of the study period (median 11 starts, range 1–49 starts, Q1 6, Q3 17). There was no significant difference in the average number of starts between horses with any MFC grade ($p = 0.1$) (Table S7).

3.4.5 | Earnings

Median total earnings were $32 253 per horse (mean $69 445, range $0–$3 750 000, Q1 $9166, Q3 $73535) for the 2119 horses that raced. Median earnings per start for the same horses were $2674 (mean $5856, range $0–$268 614, Q1 $1112, Q3 $5901). There was no significant association between total earnings ($p = 0.78$), or earnings per start ($p = 0.9$) and any MFC grade. Back-transformed estimates and CIs for average earnings and earnings per start are provided in Tables S8 and S9.

3.4.6 | Performance calibre

The distribution of Career Best Starts for all 2119 horses that raced was as follows: 84% raced but did not reach Listed or Group level. 4.8% had their highest start in a Listed race. 4.2% had their highest start in a Group 3 race. 3.1% had their highest start in a Group 2 race. 4.3% started a Group 1 race. No significant associations were found between any MFC grade and Career Best Start ($p = 0.45$), nor Weighted Listed and Group Starts $p = 0.1$. For Class Performance Index, the median CPI in 1996 horses for which it was available was 0.70 (mean 1.47, range 0–88). There were no significant associations between CPI and any MFC grade ($p = 0.3$).

3.4.7 | Racing performance for axial MFC lucencies

Of the seven yearling sale horses with axial MFC lucencies, six started at least one race and all six placed; including four who won at least one race. Five first raced as 2-year-olds and one was exported as a 2-year-old then subsequently raced. The age at first race ranged from 812 to 1003 days. The total number of starts ranged from 6 to 21 races. Total earnings ranged from $6330 to $126 826 and earnings per start ranged from $1055 to $14 092. Four had available CPIs, ranging from 0.23 to 3.42. Follow-up communication for the one horse with an axial MFC lucency that did not race revealed that the filly was involved in a fatal accident during breaking in.

3.4.8 | Racing performance for 2-year-old grade 3 MFC SCLs

The above racing performance outcomes refer to yearling sales radiograph findings. The five horses with grade 3 MFC SCLs at 2-year-old sales all went on to start at least one race. Their average number of starts was 15.2, average number of wins was 2.2, median earnings per start were $1717 (mean $2928) and median total earnings were $36 064 (mean $35 442).

4 | DISCUSSION

This study has documented the prevalence of MFC SCLs in a prospective convenience sample of yearling and 2-year-old Thoroughbreds presented for sale at public auctions. It is part of the largest sales radiology study to date and the first time that MFC SCLs have been studied longitudinally in horses presenting for sale at 1 and 2 years of age.

It is the first study to sample from all repository radiographs using consignors' permission for enrolment and to subsequently analyse associations between radiological findings and racing performance. Obtaining research consent for 74% of yearlings with repository radiographs and 78% of eligible 2-year-olds exceeded expectations and reflected a strong desire within the Thoroughbred industry to add to the evidence base regarding the significance or otherwise of MFC SCLs in sales horses. Previous sales studies have sampled up to 47% of radiographs.[4–6] The majority of previous sales radiology research has retrospectively utilised sales radiographs acquired by a limited number of veterinary practices and thus a select sample of consignors.[8,12,13] The current study enrolled horses from 71 different yearling consignors and 45 2-year-old consignors, thereby sampling a range of management practices and sales preparation systems. Earlier studies could not all include the minimum three radiographic projections that are necessary for MFC evaluation, which were available for this study.[4,5,13,20]

The prevalence of MFC SCLs found here is similar to values reported in previous Thoroughbred sales radiology work, bearing in mind differences in the classification of lucency size and appearance. Grade 3 MFC SCLs, that is, large cystic lesions, were found in 1.0% of yearlings and 1.1% of 2-year-olds, which is consistent with previous reports of 0.86%[9] to 1.7%[15] in yearlings and 0.84% in 2-year-olds.[6] Previously reported prevalences of MFC SCLs most equivalent to the grade 2 defined in this study range from 0.93%[9] to 3.9%[4] in yearlings; grade 2 MFC SCLs are reported here in 1.8% of yearlings and 3.2% of 2-year-olds. MFC SCLs most equivalent to the grade 1 defined in this study were previously reported in 6.4%[5] and 10.7% of yearlings.[4] The current results show grade 1 MFC SCLs in 6.8% of sales yearlings and 6.9% of sales 2-year-olds.

A right hindlimb predilection, seen for grade 2 and 3 MFC SCLs in both yearlings and 2-year-olds, is consistent with previous reports.[3–5,8,21,22] This study found approximately two-thirds of yearling grade 2 and 3 MFC SCLs were in the right stifle (65.5% and 66.7%, respectively). In 2-year-olds, at least 80% of grade 2 and 3 MFC SCLs were in the right stifle (82.4% and 80.0%, respectively). The reasons for this predisposition are unknown, but may relate to some form of low-grade stress to that particular side due to horses' predominant direction of movement during exercise.

Results show similar percentages of each grade of MFC SCL between colts or geldings and fillies, both in yearlings and 2-year-olds, as reported previously.[14] This study controlled for horse sex in all regression analyses of racing performance because there are differences in racing performance and racing opportunities between colts, fillies and geldings, whereby horses with breeding value are often retired earlier than their gelding counterparts.

The sample of yearlings studied represents 10.9% of all registered North American foals born in 2015 and 36% of all yearlings sold at auction in North America in 2016. The prevalence of MFC findings refers specifically to the sales population. The prevalence in the entire population is likely to be greater due to sales selection pressure. This is supported by studies including both sale and nonsale yearling radiographs that report a prevalence of 4.3%–7.8% for MFC SCLs.[3,21]

The grading scale used in this study was modified from previously published systems.[22,23] A flattened radiological appearance of the MFC has been debated, both in terms of whether it is real and whether it is important. Projection angle, radiographic technique and hindlimb stance affect MFC shape on resulting images.[19] Flattening of the distal contour of the MFC was previously recorded in 52% of 1505 Thoroughbred sales yearlings,[4] suggesting a finding affecting approximately half the population is unlikely to be pathological. A recent study considered MFC flattening without deeper sclerosis to be normal and did not include it as an abnormality.[3] In the current study, flattening of the distal articular contour of the MFC, in the absence of radiolucent subchondral change, was considered to be within normal limits (grade 0). Of 800 grade 0 yearling MFCs, which included flattening, 97% remained grade 0 as 2-year-olds.

Education in application of the radiological grading system was important. Following a period of training in the use of the grading scale, its application was shown to have excellent interobserver agreement ($K\alpha = 0.94$). Analysis demonstrated perfect agreement ($k = 1.00$) in identifying grade 0 MFCs and grade 3 MFC SCLs and occasional differences in categorising grade 1 and 2 MFC SCLs but still moderate to substantial agreement ($k = 0.57$ and $k = 0.62$, respectively).[24] Variation for grades 1 and 2 may arise from the use of a 3 mm depth threshold, where borderline lucencies are classified according to an observer's opinion of the overall appearance as either a shallow, crescent-shaped or a moderate, dome-shaped lucency, in addition to the exact depth. Variability in radiopacity or sclerosis surrounding SCLs was intentionally not included in this grading system.[3] The image zoom function was used to increase measurement accuracy using DICOM viewing software tools. Horses were all Thoroughbreds of similar age and size, as opposed to different breeds or the inclusion of foals or weanlings, where it becomes necessary to use a ratio of affected MFC distance rather than absolute measurements.[5]

Lucencies located in the axial aspect of the MFC, adjacent to the medial intercondylar eminence of the tibia, were categorised separately from SCLs located in the central, weightbearing portion of the MFC because in the authors' experience these have a different risk profile. These were referred to as lucencies rather than cystic lesions because there tends not to be an obvious communication with the joint and the histological features are unknown. Axial lucencies are reported to occur at an earlier age than central MFC SCLs, and their documented resolution in 8 of 8 Thoroughbred foals by 12 months of age suggests that many may resolve prior to yearling sales.[3] The current results support evidence that some do persist and present as spherical or ovoid axial lucencies in yearlings and 2-year-olds.[14] No new axial MFC lucencies developed in 2-year-olds that were not already present at yearling age in the horses studied. None of the seven affected horses in this study had reduced racing performance because of an axial lucency. It is recognised that axial lucencies within the femoral condyles can occur in association with proximal tibial SCLs,[25] but on their own they do not appear to be a clinical concern.

The time period between North American yearling and 2-year-old sales ranges from 6–9 months. Although numbers of pinhooked yearlings with grade 2 and 3 MFC SCLs are small, the results document

evidence of an unchanged appearance or a one grade improvement in 8 of 10 yearling grade 2 MFC SCLs by 2-year-old sales, and a one grade improvement in 2 of 3 yearling grade 3 MFC SCLs. The study could not address whether any yearlings with grade 3 MFC SCLs may have had surgical intervention postsale that contributed to their ability to race.[11]

There are two scenarios in which a horse intended for sale may be subject to negative selection pressure for reasons related to MFC SCLs. The first is the onset of clinical lameness, either between birth and yearling age, or during yearling or 2-year-old sale preparation. It is recommended practice that horses intended for sale are withdrawn if they develop an overt lameness. Horses are assessed at the walk at yearling sales, whereas 2-year-olds undergo a timed presale gallop after a minimum of 90 days of training. Analgesic use could not be accounted for in this study.

The second scenario occurs after acquisition of screening or repository radiographs, when the consignor receives a radiology report. Severe lesions that may affect sale value can result in withdrawal from sale prior to submission of radiographs. The study results reflect the distribution of lesions only in horses entered for sale and may underestimate the prevalence of severe lesions in nonsale Thoroughbreds. The associations with racing performance reported in this study should be applied to horses presented for sale at auction and are not applicable to horses with clinical lameness at yearling or 2-year-old age attributed to MFC lesions.

The number of yearlings with a grade 3 MFC SCL is relatively small at 26 horses. However, this equals the highest number of MFC cystic lesions studied previously.[4] The current results show that fewer yearlings with grade 3 SCLs go on to race, but in those that do race there is no evidence of worse performance compared with unaffected peers. Despite not meeting the threshold for statistical significance, there is a clinically relevant difference in that grade 3 yearlings had a 78% probability of racing (20 of 26), which was lower than the overall proportion of 85% yearlings that raced (2119 of 2508) and lower than the 84% probability of horses with a grade 0 MFC SCL racing (1909 of 2266).

The goal of this research was to translate results into practical advice that veterinarians can give to consignors and prospective purchasers. Veterinary advice must consider a client's particular needs, including his or her intentions for a given horse and personal level of risk tolerance. Individual client's needs will never be identical and neither will the decisions different clients make based on certain radiological findings. The veterinarian's role is to accurately identify lesions and provide evidence-based information as to the associated risk. The provision of objective data will increase consignors' and purchasers' ability to make evidence-based decisions on sales horses. For example, if a prospective buyer understands that the presence of a grade 3 MFC SCL in a sales yearling increases the horse's probability of not making it to the races from 16% to 22%, that is, from a 1 in 7 to a 1 in 5 chance of not racing, and it may or may not need treatment to do so, it is then up to the client to decide the weight of importance that finding carries for a given purchase.

Of arguably greater importance than the identification of severe lesions is the documentation of common, mild findings that have no detrimental impact on racing performance and a low incidence of progression. This applies strongly to the grade 1 MFC SCL results. The least positive outcome of the sales repository system is when minor radiological findings of no consequence to the horse result in failed sales, or sale prices that do not reflect the horse's value, when the horse may go on to perform exceptionally well. The intention of undertaking a large, sales-based study was to provide veterinarians with objective evidence that frees them from being unnecessarily critical about certain radiological findings in young Thoroughbreds.

The main limitations of this study arise from its use of convenience sampling of horses presented for sale at public auction. Results are likely to underestimate the prevalence of severe, clinical MFC lesions in the nonsale population. The study design could not address unknown losses between weanling screening and yearling age, and between yearling and 2-year-old age in horses intended for resale. However, this also ensures that the findings are specifically applicable in the repository environment to future populations of horses that have made it to the sales. Some effects of sex may be missed by not analysing the performance of entire males and geldings separately. Grouping the male subsets together was necessary due to gelding occurring at a range of ages after commencement of racing.

Overall, MFC SCLs of varying grades were observed in 9.6% of Thoroughbred yearlings and of 11.2% of 2-year-olds. Shallow, crescent-shaped lucencies (grade 1) were the most common type of MFC SCL in both age groups. The majority of grade 1 MFC SCLs seen in sales yearlings were no worse at 2-year-old sale presentation; 19.4% of yearling grade 1 MFC SCLs progressed to a deeper, dome-shaped lucency (grade 2) by 2 years of age and the rest either remained unchanged or resolved. It was also possible for grade 2 and 3 MFC SCLs to improve one grade in appearance between yearling and 2-year-old sales.

Although fewer sales yearlings with a grade 3 MFC SCL made it to the races, no statistically significant difference was found. When horses with a grade 3 MFC SCL as a yearling did race, there was no evidence of worse racing performance compared to unaffected peers. All horses that presented at a 2-year-old sale with a grade 3 MFC SCL raced, though this sample size was small. Axial MFC lucencies did not affect racing performance.

AUTHOR CONTRIBUTIONS

Frances J. Peat, C. Wayne McIlwraith, Christopher E. Kawcak, Jeffrey T. Berk and David P. Keenan contributed to study conception and design, study execution and data acquisition. Daniel S. Mork and Frances J. Peat performed data analysis. Frances J. Peat prepared the manuscript. All authors contributed to data interpretation, manuscript revision and approval of the final manuscript.

ACKNOWLEDGEMENTS

We thank Keeneland Association Ltd., Fasig-Tipton Ltd and Ocala Breeders' Sales Company Ltd for supporting this research to proceed at their sales, for their assistance in obtaining consignor consent and facilitating radiograph collection. We extend our utmost thanks to all 116 consignors who made horses available for the study. For their

expertise in similar previous research and advice on study design, we acknowledge and thank Debbie Spike-Pierce, Larry Bramlage, Sarah Plevin and Jonathon McLellan. For statistical expertise and guidance, we thank Ann Hess.

FUNDING INFORMATION

Grayson-Jockey Club Research Foundation, Keeneland Association Ltd, Fasig-Tipton Ltd and significant private donations from Barbara Banke, Bridlewood Farm, Flaxman Holdings, Maria Niarchos, John and Jerry Amerman, Foxwood Stables, Three Chimneys Farm, Ashford Stud, John Magnier, Dr Mark Dedomenico, Consignors & Commercial Breeders Association (Lexington, Kentucky), Marty & Pam Wygod, Gary West, and Dr Ryan Carpenter, as well as Antony Beck, Gainesway Farm, Spendthrift Farm, Denali Stud and Victoria Chapman.

CONFLICT OF INTEREST STATEMENT

No competing interests have been declared.

PEER REVIEW

The peer review history for this article is available at https://www.webofscience.com/api/gateway/wos/peer-review/10.1111/evj.13945.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ETHICAL ANIMAL RESEARCH

Research ethics committee oversight not currently required by this journal: procedures were performed as part of clinical investigations.

INFORMED CONSENT

Signed informed consent was obtained from yearling and 2-year-old consignors for inclusion of horses in the study and access to horses' radiographs for the purpose of this study.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Peat FJ, Kawcak CE, McIlwraith CW, Keenan DP, Berk JT, Mork DS. Subchondral lucencies of the medial femoral condyle in yearling and 2-year-old Thoroughbred sales horses: Prevalence, progression and associations with racing performance. Equine Vet J. 2023. https://doi.org/10.1111/evj.13945